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Climate aridity in southern Bulgaria for the period 1961-2015

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Abstract

The climate change on a global, regional and local scale is one of the largest problems indicated by the 21st century studies. Some of the major climate changes on the Balkan Peninsula, and in particular in Bulgaria, are related to rising temperatures and decreasing precipitation, which leads to drought and climate aridity. The present study focuses on the investigation of the climate aridity in the non-mountainous part of Southern Bulgaria in order to assess the aridity condition in temporal and spatial scale. The main investigated period is 1961-2015 and the reference periods are 1961-1990 and 1986-2015. The aridity is analysed on the basis of monthly data for air temperatures and precipitation from eight meteorological stations by calculation of De Martonne aridity index and Emberger Index. The survey shows that in all the analysed meteorological stations in Southern Bulgaria there are periods which display characteristics of the semiarid or arid climate. The aridity is well-expressed in the southwest part of Bulgaria (station Sandanski) and the western part of the Thracian lowland (station Plovdiv). Despite the aridity conditions established in the investigated region the tendencies in multiannual variability of De Martonne and Emberger indices show decreasing of aridity during the last 30 years (1986-2015) of the investigated period.

Keywords: *aridity, climate change, Southern Bulgaria, De Martonne Aridity Index, Emberger Index*

Rezumat. Ariditatea climatică în sudul Bulgariei în perioada 1961-2015

Schimbările climatice la scară globală, regională și locală sunt una dintre cele mai mari probleme indicate de studiile secolului XXI. Unele dintre schimbările climatice majore din Peninsula Balcanică, în special în Bulgaria, sunt legate de creșterea temperaturilor și scăderea precipitațiilor, ceea ce duce la secetă și ariditate climatică. Studiul de față se concentrează pe investigarea aridității climatice din partea non-muntoasă a sudului Bulgariei pentru a evalua starea de ariditate la scară temporală și spațială. Principala perioadă investigată este 1961-2015, iar perioadele de referință sunt 1961-1990 și 1986-2015. Ariditatea este analizată pe baza datelor lunare de temperatură a aerului și de precipitații la opt stații meteorologice prin calculul indicelui de ariditate De Martonne și al indicelui Emberger. Studiul arată că la toate stațiile meteorologice analizate din sudul Bulgariei există perioade care sunt caracteristice climatului semiarid sau arid. Ariditatea este bine exprimată în partea de sud-vest a Bulgariei (stația Sandanski) și în partea de vest a podișului tracic (stația Plovdiv). În ciuda condițiilor de ariditate stabilite în regiunea investigată, tendințele variabilității multianuale ale indicilor De Martonne și Emberger arată scăderea aridității în ultimii 30 de ani (1986-2015) din perioada investigată.

Cuvinte-cheie: *ariditate, schimbare climatică, Bulgaria de Sud, indicele de ariditate De Martonne, indicele Emberger*

Introduction

The study of the climate aridity could give important information about the condition for natural vegetation and agricultural plants. Aridity and drought are not equal concepts. Aridity, in contrast to drought, is a constant feature of the climate in a given area with low rainfall, resulting in a number of problems such as water scarcity. The aridity is a result of large-scale sustainable atmospheric and oceanic circulations or regional geographic features of the topography (Maliva and Missimer, 2012). The study of the aridity is based in large periods (at least 30 years), while the study of the drought is performed in small periods, which is a consequence of its occasional character. According to Maliva and Missimer (2012) there are four basic reasons for the existence of the arid climate: constant anticyclones with a combination of trade winds; continental air masses with low humidity; orographic shadow and cold ocean currents.

The existing publications show that the aridity has been investigated by various complex climatic indices. One of the most common indices for aridity research is the Thornthwaite climate index (moisture index). According to this index, aridity is shown in several tropical and subtropical areas of the world, being represented in Europe only in small parts of the south and southeast of the Iberian Peninsula (Feddema, 2005). In the last years, many studies revealed the existence of aridity and water scarcity in many areas of the Mediterranean and the Balkan Peninsula: Nastos et al. (2013), Rego and Rocha (2014), Andrade and Corte-Real (2016), Chendeș (2010), Vlăduț et al. (2017). According to Topliisky (2006) the aridity is characteristic for almost 2/3 of the plains of Bulgaria and can be observed well in the period June - October. Nikolova and Mochurova (2012) point out the tendency to arid climate during late summer and beginning of autumn in many region of Bulgaria. The De Martonne and Thornthwaite indices are used by Mitkov and

Topliiski (2018) who have determined the tendencies to arid or semi-humid climate in Bulgaria.

The aim of present paper is to analyse spatial and temporal variability of aridity condition in South Bulgaria. In order to achieve this aim two climatic indices (De Martonne aridity index and Emberger index) are calculated and the years with the extreme values of the indices are determined. The tendency in temporal variability in both indices is reveal.

Studied area, data and methods

In order to assess the aridity condition in temporal and spatial scale the present study focuses on the investigation of the climate aridity in non-mountainous part of Southern Bulgaria (Fig. 1) which is one of the main agricultural areas in the country. The main investigated period is 1961-2015 and the reference periods are 1961-1990 and 1986-2015. The aridity is analysed on the basis of monthly data for air temperatures and precipitation from eight meteorological stations (Table 1) by calculation of the De Martonne aridity index and Emberger Index.

The selection of the stations and the duration of the investigated period are determined by the availability of monthly precipitation data. The sources of monthly data are the Meteorological yearbooks (National Institute of Meteorology and Hydrology, Bulgaria) and the Statistical yearbooks (National Statistical Institute, Bulgaria).

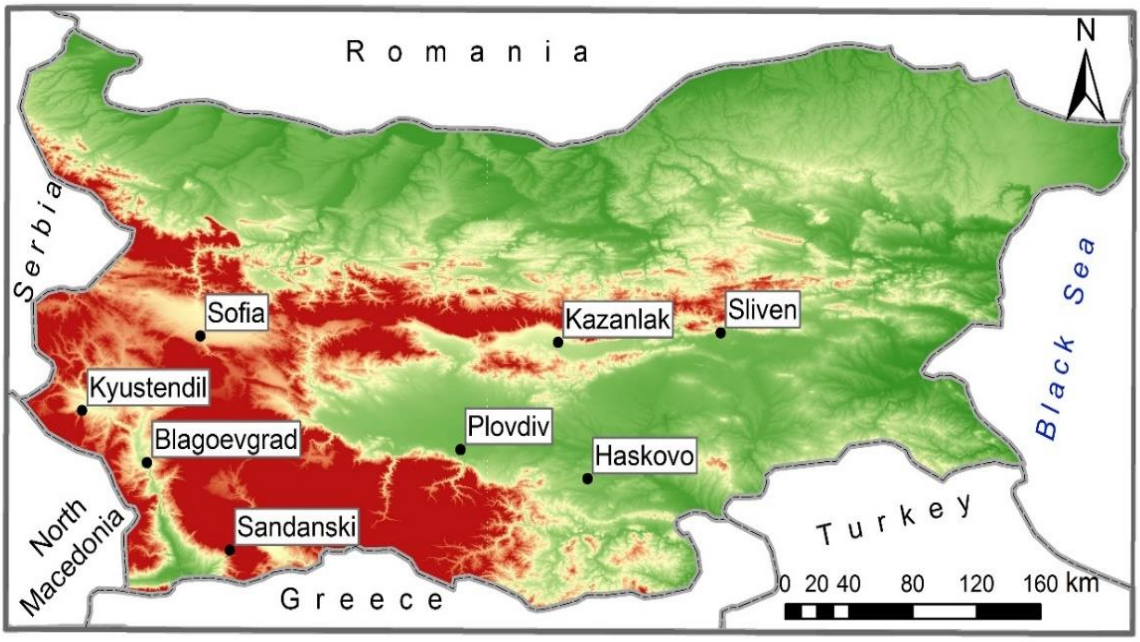

Fig. 1: Location of the studied meteorological stations *(Base map SRTM digital elevation model, NASA JPL, 2013)*

Table 1 List of meteorological stations used in the survey

Meteorological station	Latitude	Longitude	Altitude /m/
Sandanski	41º33′	23º16′	296
Blagoevgrad	42º00′	23º05′	410
Kyustendil	42º16′	22º43′	560
Sofia	42º39′	23º23′	500
Kazanlak	42º37′	25º24′	407
Plovdiv	42º04′	24º51′	164
Haskovo	41º55′	25º34′	203
Sliven	42º40′	26º19′	243

The analyses have been made using empirical and statistical methods. The De Martonne aridity index is one of the first indices used to assess aridity. The index was created by the French geographer Emmanuel de Martonne in 1926. In recent years there are many publications, based on De Martonne's aridity index in Greece (Mavrakis and Papavasileiou, 2013), Bulgaria (Mitkov and Topliiski, 2018), Romania (Vlăduț et al., 2017), Turkey (Chendeș, 2010), etc.

The annual values of the De Martonne index (Ia) are calculated using the following formula:

$$Ia = \frac{P}{T + 10}$$

where:
P - the annual precipitation totals
T - the average annual air temperature
10 - coefficient used to acquire positive values

The acquired results can be related to the following climate types, according to the De Martonne index (Table 2).

Table 2 Climate types according to DeMartonne aridity index

Climate types	De Martonne index values
Arid	< 10
Semi-arid	10 – 20
Mediterranean	20 – 24
Semi-humid	24 – 28
Humid	28 – 35
Very humid a	35 – 55
Very humid b	> 55

Source: Baltas (2007), Nikolova (2018)

The Emberger index is based on data from rainfall sums and average monthly air temperatures of the coldest month and warmest month (Emberger, 1930). Emberger used this index to classify phytoclimatic regions. That is why some scientists investigate the dissemination of vegetation according to the Emberger index (Gavilán, 2005 in Spain; Savo et al., 2012 in Italy). The Emberger Index (IE) is calculated using the following formula:

$$IE = \frac{100.P}{M^2 - m^2}$$

where:
P - the annual sum of rainfall
M - the monthly average temperature of the warmest month
m - the average monthly air temperature of the coldest month

The climate types according to the Emberger index are the following (Table 3):

Table 3 Climate types according to Emberger index

Climate areas	Emberger index values
Arid	< 30
Semi-arid	30 – 50
Semi-humid	51 – 90
Humid	> 90

Source: Nikolova (2018)

The temporal variability of aridity is analysed by application of linear regression model ($y=b_0+b_1*x$) of the time-series of both investigated indices (De Martonne aridity index and Emberger index). The statistical significance of the trend is determined by T-test using AnClim software (Štěpánek, 2008). Also, to obtain more information about the aridity in Southern Bulgaria and in particular about the causes of this climate characteristic, a correlation was made between the data for the De Martonne and Emberger indices and the North Atlantic Oscillation (NAO) and the Western Mediterranean oscillation (WeMOI).

The impact of NAO and MOI on the climate of Europe, including Bulgaria, are active throughout the year, but are best expressed in the cold half of the year (Hurrell, 2000; Martin-Vide and Lopez-Bustins, 2006). The NAO represents the difference in sea level atmospheric pressure between Iceland and the Azores. When NAOI is positive western winds are stronger and the winter in southern Europe are a colder and drier. The negative NAOI determine wet and warmer winters in southern Europe. The WeMOI is determined as an air pressure difference between Padua and Cadiz. The positive WeMOI is related to the anticyclone over the Azores and low-pressures in the Liguria Gulf. The negative phase coincides with the anticyclone located over the central Europe (Martin-Vide and Lopez-Bustins, 2006). The NAOI are taken from Hurrell Station-Based dataset[1] and WeMOI are from Climate Research Unit[2].

Results and discussion

Aridity indices – average and extreme values

The present study of aridity in South Bulgaria is based on calculations of the De Martonne aridity index and Emberger Index. According to the De Martonne index the average values for three investigated periods 1961-2015, 1961-1990 and 1986-2015 show humid and semi-humid climate while for the meteorological stations in Sandanksi and Plovdiv the indices are constantly associated with the Mediterranean climate (Table 4). This fact can be also interpreted as a geographical expansion to the north of the Mediterranean climate. In most of the investigated stations the average values of the Emberger index show humid climate (Table 5) while De Martonne index indicates semi-humid climate. The difference between the two types of indices is biggest for stations Sandanski where the De Martonne index shows Mediterranean climate and according the Emberger index the climate is

[1] https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based
[2] https://crudata.uea.ac.uk/cru/data/moi/

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semi-arid. The second station with different results is Plovdiv–De Martonne index indicates Mediterranean climate while Emberger index shows humid and semi-humid climate. Despite different 30-years periods Nikolova and Voisilova (2013) have found similar results for De Martonne aridity index in South Bulgaria, which indicate slight changes in the multi-annual course of the indices.

Table 4 Climate types during various periods based on the De Martonne aridity index

Meteorological station	1961-2015	1961-1990	1986-2015	Lowest values	Year of lowest values
Sofia	29,00	27,7	29,02	12,47	1990
				14,14	2000
Kazanlak	26,98	26,58	26,18	14,77	2000
Sliven	27,44	25,46	28,25	16,90	2008
Kyustendil	27,58	27,93	26,90	14,3	2000
Blagoevgrad	24,08	24,79	23,12	9,79	2000
Plovdiv	23,67	23,28	22,92	11,00	2001
Sandanski	20,67	20,33	20,45	9,52	2000
				9.59	1993
Haskovo	29,25	29,62	27,99	16,03	2008

Climate types

Arid	Semi-arid	Mediterranean	Semi-humid	Humid

The average values of the De Martonne index indicate mainly semi-humid and Mediterranean climate during different periods (Table 4). Semi-humid climate is established also by Vlăduț et al. (2017) for the period 1961-2015 in the lowlands and plains in the north part of Bulgaria and south of Romania. On the other side, annual values of the index show that in some of the stations located in south-west part of the study area the aridity conditions have been observed in 22 to 45 % of the investigated years. These are stations which show a Mediterranean type climate according to the 30-years average values: Blagoevgrad (22% of the years with arid or semi-arid conditions), Plovdiv (35 %) and Sandanski (45 %). Based on potential evapotranspiration Nastos et al. (2013) show the tendency to sub-humid and semi-arid climate in many areas, mainly in eastern Greece.

The index values for the 90-es and the beginning of the 21st century are the lowest and in some cases are equivalent to arid climate (Blagoevgrad and Sandanski according to the De Martonne index; Sandanski, Blagoevgrad, Plovdiv and Kyustendil according to the Emberger index), Tables 4 and 5. The peculiarity of the results is that both indices (De Martonne index and the Emberger index) indicate as the most arid year the year 2000 for which the lowest values of the indices are obtained (Tables 4 and 5).

Table 5 Climate types during various periods based on Emberger index

Meteorological station	1961-2015	1961-1990	1986-2015	Lowest values	Year of lowest values
Sofia	124,65	126,56	118,52	39,67	2000
Kazanlak	115,45	120,93	105,21	42,08	2000
Sliven	105,9	110,38	102,92	59.22	2013
Kyustendil	117,8	124,69	107,77	26,72	2000
Blagoevgrad	95,87	104,29	85,52	22,57	2000
Plovdiv	90,89	94,12	83,11	22,36	2001
Sandanski	69,89	74,71	64,51	28,03	2000
				28.23	1993
Haskovo	111,84	119,67	108,44	48,24	2000

Climate types

Arid	Semi-arid	Semi-humid	Humid

The De Martonne Index characterizes climate aridity but is also applied to assess the suitability of the climate for the development of natural vegetation. According to Satmari (2010), the Mediterranean and semi-humid climates with the De Martonne indices 20-25 and 25-30 are favourable for steppe vegetation. According to the results obtained in the present study, the stations are grouped into two groups: 1) with index 25-30 and 2) with index 20-25. In the first group are the territories with semi-humid climate, which are favourable for high grass steppes. This group of stations includes the stations located mainly in central Bulgaria (the Sub-Balkans valleys) and Haskovo station located in south-eastern Bulgaria in the lower part of the Eastern Rhodope Mountains.

The second group of stations, according to the De Martonne Index, is characterized by a Mediterranean climate and favours the development of grass or woody plants with hollow stems and long narrow leaves. These conditions are observed in the middle and lower Struma River valley (southwestern Bulgaria) and in the central parts of southern Bulgaria (station Plovdiv in the Upper Thracian valley).

Trend of aridity indices

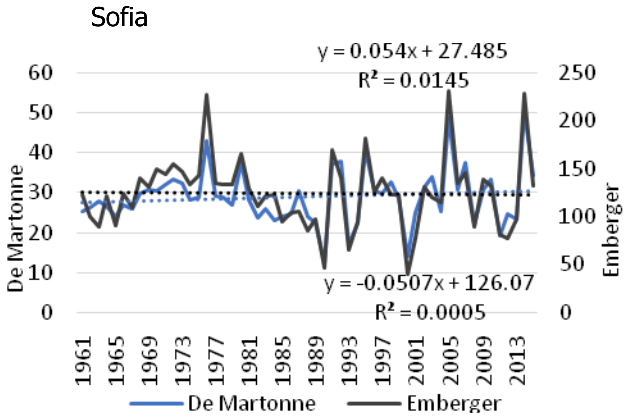
In order to study multiannual variability of aridity conditions the linear regression was applied to the time series of the De Martonne and Emberger aridity indices for two periods: 1961-2015 and 1986-2015. For the period 1961-2015 the trend of Emberger index is negative and the similar tendency show four meteorological stations (Blagoevgrad, Kyustendil, Kazanlak and Haskovo) for de Martonne index. The negative trend is statistically significant only for Emberger index at station Haskovo. The multiannual courses show quite good synchronicity between the De Martonne and Emberger indices (Fig. 2.). Mitkov and Topliiski (2018) have established the negative trend of the De Martonne index for the period 1900–2016 in selected stations from the non-mountainous part of Bulgaria. The decreasing trend in the aridity index could be explained by increasing of air temperature and decreasing of precipitation (Tabari et. al., 2014; Chenkova and Nikolova, 2015).

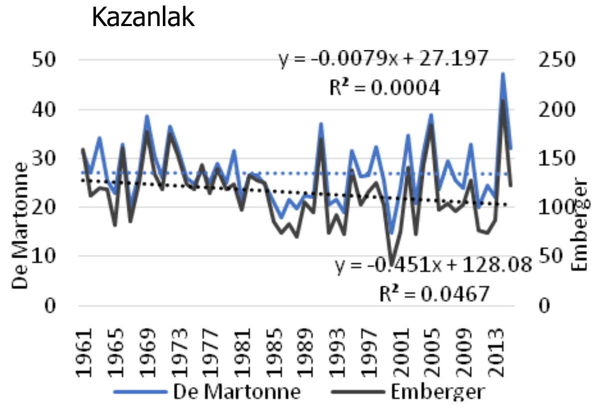
In the last 30 years (1986-2015) the tendency of aridity indices has changed and the trend for both indices in all of the investigated stations is positive (Table 6). Four stations, situated mainly in the western part of the studied area (Blagoevgrad, Kyustendil, Sandanski and Plovdiv) show statistically significant trend. The positive trend indicates the decreasing of aridity during the period 1986-2015. On the other side Cheval et al. (2017) indicate significant tendency towards more arid climate in the eastern part of Balkan Peninsula, including Bulgaria for the period 2021-2050 in comparison to 1961-1990.

Table 6 Trend of aridity indices for the period 1986-2015

	Blagoevgrad	Kazanlak	Kyustendil	Plovdiv	Sandanski	Sofia	Sliven	Haskovo
De Martonne	-0.05	-0.08	-0.24	0.24	0.38	0.54	0.91	-0.35
Emberger	**3.85**	**3.06**	1.35	**3.82**	**2.76**	2.51	2.41	2.26

Values marked in Bold are statistically significant at p=0.05





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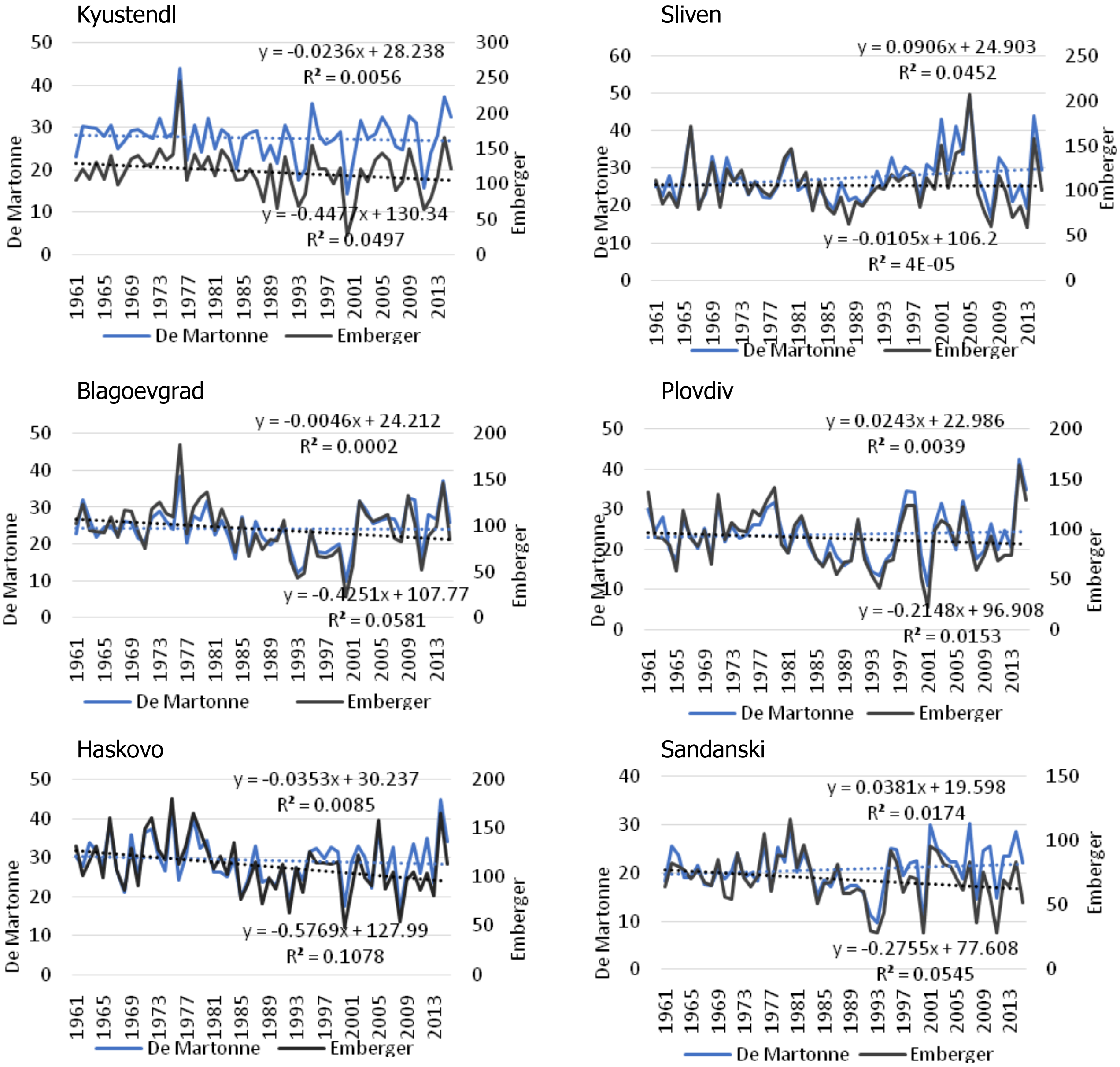

Fig. 2: Multi-annual variability of aridity indices

Impact of atmospheric circulation on aridity conditions

In order to analyse the impact of atmospheric circulation on aridity conditions the correlation coefficients between aridity indices and annual values of two circulation indices (NAOI and WeMOI) are calculated. The results show negative and statistically non-significant correlation. The correlation coefficients between NAOI and De Martonne aridity indices are higher than the coefficients for the Emberger indices (Table 7).

Compared to the period 1961-2015, a slight increase in the correlation coefficients between the aridity indices and the circulation indices is observed during the period 1986-2015. The relationship between WeMOI and aridity indices is better determined for the last 30 years (1986-2015) of the investigated period and mainly for the stations in the Upper Thracian valley and in the western Sub-Balkans valleys.

Table 7 Correlation between aridity indices and annual values of NAO and WeMOI

	Sofia	Kazalak	Sliven	Kyustendil	Blagoevgrad	Plovdiv	Sadanski	Haskovo
De Martonne Aridity Index ()								
1961-2015								
NAO	-0.17	-0.15	-0.21	-0.21	-0.25	0.04	-0.26	-0.21
WeMOI	-0.17	-0.07	-0.08	-0.03	0.08	-0.09	0.00	0.03
1986-2015								
NAO	-0.23	-0.13	-0.27	-0.23	-0.24	0.07	**-0.37**	-0.28
WeMOI	-0.22	-0.23	-0.06	-0.21	**-0.40**	-0.29	-0.14	-0.29
Emberger Aridity Index								
1961-2015								
NAO	-0.10	-0.09	-0.21	-0.09	-0.20	0.06	**-0.31**	-0.12
WeMOI	-0.08	0.03	0.07	0.05	0.10	0.01	0.27	0.18
1986-2015								
NAO	-0.16	-0.06	-0.23	-0.10	-0.15	0.12	**-0.37**	-0.17
WeMOI	-0.27	-0.25	-0.06	-0.28	**-0.38**	-0.32	0.04	-0.28

According to T-statistic the values in Bold are statistically significant at p=0.05

The statistical significance of the correlation is confirmed only in two stations (Blagoevgrad and Sandanski), located at the Struma river valley in the south-western part of Bulgaria.

The different correlation between atmospheric circulation indices and aridity indices can be explained by the relationship between parameters used for the calculation of aridity indices and also by the fact that annual values of air temperature and precipitation are used for the calculation of the De Martonne index while the Emberger index is based on the monthly air temperature for the warmest and the coldest months. We have selected the annual values of the atmospheric circulation indices for the study of the correlation with Emberger indices in order to have comparability with the results of the analysis of the correlation between De Martonne aridity index and atmospheric circulation. On the other hand, Emberger's formula also includes annual values - for precipitation totals. The results of the present study show that future investigation of the relationship between Emberger index and NAOI and WeMOI have to be directed to the analysis on monthly level.

Conclusion

The present study analyses the aridity conditions in non-mountainous part of south Bulgaria where the climate is transitional between moderate continental and Mediterranean. Based on the calculation of De Martonne aridity index and Emberger index for the period 1961-2015 and two 30-years periods (1961-1990 and 1986-2015) the following conclusion can be drawn:

- For all investigated periods the Emberger index shows mainly humid climate while according to the De Martonne index the climate in the investigated area is mainly semi-humid and, in some stations, – Mediterranean. The Mediterranean climate is characteristic for the south-western part of Bulgaria but also expanding to the north, occupying the middle part of the Struma river valley and central part of southern Bulgaria (Upper Thracian plain, station Plovdiv).
- The year 2000 makes impression with arid or semi-arid conditions in all of the investigated stations. On the background of general positive trend of aridity indices, the occurrence of the years with arid or semi-arid climate during the last decades increases.
- Despite the slight positive trend of aridity indices during the last 30 years (1986-2015) of the investigated period the aridity is a feature in many parts of the investigated area: the region of the middle and low Struma valley (Blagoevgrad and Sandanski) and Upper Thracian plain (Plovdiv) which will suffer from the consequences of aridity.

The relation between aridity indices and atmospheric circulation is better determined for the De Martonne index than for the Emberger index. However, the correlation coefficients are not statistically significant which require to direct future study to other factors that impact the aridity conditions e.g. solar radiation, topography, land use etc.

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